Data Cleaning for RFID and WSN Integration

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***Abstract*—Today's manufacturing environments are very dynamic and turbulent. Traditional enterprise information systems (EISs) have mostly been implemented upon hierarchical architectures, which are inflexible to adapt changes and uncertainties promptly. Next-generation EISs must be agile and adaptable to accommodate changes without significant time delays. It is essential for an EIS to obtain real-time data from the distributed and dynamic manufacturing environment for decision making. Wireless sensor networks (WSNs) and radio-frequency identification (RFID) systems provide an excellent infrastructure for data acquisition, distribution, and processing. In this paper, some key challenges related to the integration of WSN and RFID technologies are discussed. A five-layer system architecture has been proposed to achieve synergistic performance. For the integration of WSN and RFID, one of the critical issues is the low efficiency of communication due to redundant data as redundant data increases energy consumption and causes time delay. To address it, an improved data cleaning algorithm has been proposed; its feasibility and effectiveness have been verified via simulation and a comparison with a published algorithm. To illustrate the capacity of the developed architecture and new data cleaning algorithm, their application in relief supplies storage management has been discussed.**

***Index Terms*—Data cleaning, enterprise information system (EIS), industrial informatics, networks, radio-frequency identification (RFID), system architecture, system integration, wireless sensor network (WSN).**

I. Introduction

MANUFACTURING is the cornerstone of the modern industrialized society. A strong manufacturing industry is crucial to economy as it stimulates numerous economic sectors [1]. Manufacturing systems are very complex networks consisting of numerous objects, decision-making units, materials, and information flows. Therefore, enterprise information systems (EISs) are needed as technology platforms that enable the enterprises to integrate and coordinate their business processes at both intra-organizational and inter-organizational levels. The technological advances in EIS have provided a viable solution to the growing needs of information integration in both manufacturing and service industries [2]. Traditionally, EISs have mostly been developed as centralized systems to ensure that information can be shared across all functional units and management hierarchies. However, today's manufacturing environment has been characterized by fierce global competition, narrow marketing window, and fluctuated and fractioned supplies and demands [3]–[5]. Next-generation EISs must support the global competitiveness, innovation, the introduction of new products, and strong market responsiveness. As a result, besides the cost and quality, manufacturing systems need to become more strongly time-driven and time-oriented. This evolution requires high flexibility to adapt changes [6].

Changes and uncertainties involved in a manufacturing environment should be accompanied by the changes of EIS architecture. The needs of developing next-generation EISs have been thoroughly discussed [7]–[9]; some critical requirements for EISs including *modularity*, *sustainability*, *adaptability*, *agility*, *autonomy*, and *scalability*. Performance of the EIS greatly depends on the availability of reliable and abundant data associated with dynamic changes. In this sense, the development of an integrated information system for the real-time data acquisition is crucial to the success of an EIS. Decentralized and distributed EISs will allow a more flexible manufacturing system [10]. Wireless sensor networks (WSNs) and radio-frequency identification (RFID) systems provide excellent infrastructures to acquire, distribute, and process data in decentralized dynamic environments.

Rapid advances in industrial information integration methods have spurred tremendous growth in the use of WSNs and RFIDs for EISs [2]. With the applications of WSNs, event processing can fit well in EISs to improve the responsiveness [11]. Although WSN and RFID technologies have experienced great achievements in recent years, their applications in actual manufacturing environments are very limited. Bonivento *et al.* [12] stated that the lack of system-level design methodologies was one of the main obstacles to adopt WSNs or RFID systems in manufacturing industry. Vitturi *et al.* [13] drew a similar conclusion that the limited progress was made in the design of higher layer protocols for industrial applications of WSNs. To develop suitable WSNs for information integration of EISs in a dynamic environment, this paper focuses on the adoption of RFID systems in the WSNs and the development of new data cleaning algorithm to eliminate redundancy data effectively.

Manuscript received October 30, 2012; revised December 14, 2012 and January 26, 2013; accepted February 21, 2013. Date of publication March 07, 2013; date of current version December 12, 2013. This work was supported by the National Natural Science Foundation of China under Grant 71271013, Grant 91224007, Grant 70971005, Grant 70971004, and Grant71132008, the National Social Science Foundation of China under Grant 11AZD096, and the Quality Inspection Project under Grant 201010268 and Grant 200910088, 200910248). Paper no. TII-12-0749.

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Digital Object Identifier 10.1109/TII.2013.2250510

The remainder of this paper is organized as follows. In Section II, the progress on the development of WSNs and RFIDs is summarized; the challenges on the integration of WSNs and RFIDs are discussed. In Section III, system architecture is proposed to integrate RFID with WSNs. In Section IV, the problem of data cleaning is investigated, and a new algorithm has been introduced and validated. In Section V, an application of Integrated SWNs has been provided as a case study. Finally, in Section VI, our works have been summarized, and further works along this direction have been discussed.

II. Literature Review

A. Applications of RFIDs and WSNs

Due to the growing demands of distributed planning and scheduling of large-scale systems, computing resources tend to be ubiquitous, largely distributed, and tightly embedded in their physical environments [14]. WSNs are attractive in many embedded system applications; mainly because they do not need wired connections for communication [15]. On other hand, RFIDs are used in a wide range of industrial fields, such as factory automation, distributed and process control, traceability management, supply chain management, real-time monitoring of health, and radiation check [16], [17]. The exploitation in industrial applications is expected to increase significantly in near future, especially in the fields of logistics, automation, and control [18]. This positive trend should also be stimulated by the applications of new industrial standards such as ZigBee Alliance [19]. The next revolution in computing technology is the widespread use of small wireless computing and communication devices that will integrate seamlessly into our daily lives [20]. The EISs, such as the information systems for supply chain integration and demand chain management, require the on-demand information exchange that extends traditional results of a global database query. The information exchange involves in a large number of enterprise databases that belong to different organizations and these databases are increasingly overlapping with real-time data sources such as WSNs and RFIDs [21].

Many applications have been proposed to use WSNs and RFID for various purposes. Kim *et al.* [22] conducted a case study of using a RFID and WSN for power facility management. Wang *et al.* [23] discussed the integration of a SWN and RFID based on the de facto international standard of RFID. The core of ESN is the middleware part which is also implemented in complex event processing (CEP) technology; it can handle a large volume of events from distributed RFID and sensor readers in real time. Zeng *et al.* [24] integrated open-loop services infrastructure and RFID and then applied it to the blood management and traceability system. Poon *et al.* [25] used RFID technologies for the collection and sharing of data in a warehouse. Zhu and Sun [26] investigated a RFID and a WSN with Zigbee; electronic labels were attached to sensors to integrate the RFID with the WSN. Their systems were developed to monitor the quality of agricultural products. Shin *et al.* [27] applied the WSN in the supply chain so that project stakeholders can obtain real-time data for their decision making. Garcia-Ansola *et al.* [28] argued that an integration of RFID and WSNs was essential to ensure accurate and timely localization and tracking of objects.

B. Challenges in Integration of RFIDs and WSNs

RFID and WSNs represent two complementary technologies. RFID is widely used to identify, detect, or monitor objects. In comparison with other types of sensors, the low cost is the superior advantage of RFID; however, RFID is incapable of providing the detailed information about the conditions of objects. On other hand, a WSN can integrate logics into RFID nodes and allows an RFID system to operate in a multi-hop fashion and with the detailed information about the nodal conditions [29]. Lopez *et al.* [30] introduced a framework that operated on an integrated RFID and WSN network; similarly, Cho *et al.* [31] proposed to integrate RFID and WSN as an infrastructure for telecommunication. The tasks involved in the integration of WSNs and RFIDs are to design or select: 1) RFID tag memory; 2) WSN association protocols; 3) routing and addressing schemes; 4) RFID sensor-actuator data integration and management; 5) service definition and delivery; 6) context and service matching; and 7) distributed middleware [30]. However, the integration of RFIDs and WSNs is an emerging and immature technology; the identified challenges in promoting such integration are *energy conservation*, *real-time performance*, *data cleaning and filtering*, *Localization*, *anti-collision*, and *authentication* [32]–[37]. Due to space constraints, only the first three challenges are discussed, and the focus is on data cleaning and filtering.

1) Energy Consumption: Energy efficiency has been a crucial problem when combining RFIDs and WSNs [38]. Wireless device has a strict requirement of power consumption; sensors or RFIDs in most of existing networks have very limited battery lives. It is crucial to learn the power consumption at very early design stage [30]. Designers need it to determine system parameters, communication protocols, and functionality restrictions. The information is commonly obtained from simulation. The majority of work on energy efficient routing only focused on the efficiency factor rather than the need of achieving reliable and real-time communication [39]. Haase *et al.* [40] provided an overview over the currently simulators and methodologies. To save energy in operation, Vannucci *et al.* [41] proposed to use backscatter radio in a RFID. Transmitter for each sensor is simplified to a transistor connected to an antenna, and therefore, the cost for each sensor's communicator become negligible, while energy used for wireless communication per sensor is minimized. Zou *et al.* [42] introduced an impulse radio ultra-wideband receiver to detect energy level of sensors. Palopoli *et al.* [36] considered the problem of minimizing cost of WSNs under the constraints of energy consumption. Adaptive sampling approaches may reduce the energy consumption. Ploennings *et al.* [15] compared several adaptive sampling approaches in different applications to develop a guideline for parameterization.

2) Time Delay: As industrial networks may comprise a large number of sensors and the delay increases with the increased number of nodes. Meeting time constraints of real-time traffic in WSNs is a hard task. The main reason is that real-time devices must share the same communication medium with timing unconstrained devices. Since data from nodes is used to generate correct commands for a machine in industrial applications, time delay in data communication will cause the malfunction of machine. Bello and Toscano [43] provided a better understanding of cross-channel interference in a co-located industrial network and proposed a general methodology cross-channel interference conditions. Gamba *et al.* [44] proposed the retransmission strategies for the centralized cyclic polling-based systems over wireless channels subject to external interferences. The experiments and simulations have shown that there are alternative strategies which can reduce the rate of the failed nodes during the periodic window as compared to other strategies. Moraes *et al.* [18] proposed architecture based on a virtual token passing procedure that circulated a virtual token among real-time devices.

3) Redundant Data: The data from RFID is generally unreliable by nature; the rate of the acquired data is around 60%–70%. To obtain sufficient data, readers in the WSN interrogate tags periodically. While the issue of reading rate can be addressed, it leads to a new issue of duplicated readings; it can be a severe issue when the sensor nodes are densely distributed to ensure no area is missed between neighboring nodes. Transmitting duplicated data to data server causes the waste of energy, time delay, and other network resources [45]. It is desirable to clean data at the level of sensors and data warehousing to eliminate the redundant or unreliable data. The objective of eliminating redundant data is coupled with the reduction of energy consumption and time delay, i.e., the elimination of redundant data helps to reduce power consumption and minimize the time delay in data transmission. In the following, the algorithms for data cleaning and filtering will be focused.

C. Data Cleaning Algorithms

Data cleaning is to eliminate redundant data meanwhile maintain the integrity of original data. Some progresses have been made in data cleaning or cleaning technologies. For example, Jeffrey [46] proposed an algorithm based on the pipeline framework. Different steps of cleaning are applied based on the characteristics of the raw data. This algorithm worked well for data leakage and repeated reading. In his sequential work [47], a data cleaning strategy based on the time correlation was proposed. This algorithm used a probability model and mainly developed to solve the problem of data leakage. Sarma [48] also introduced a pipeline algorithm to improve the quality of the data flow. All of the aforementioned algorithms were developed to address the problem of unreliability of RFID data caused by data leakage and repeated readings; the problem of data redundancy has not been tackled. Carbunar [49] discussed the problem of redundant data; he suggested cleaning data by keeping inspection and silence of redundant readers. However, the proposed algorithm for detecting the device of redundant readers cannot avoid the fact that many readers have to work together at the same time. Based on the specified application, Khoussainova [50] developed a data cleaning method that relies on the application conditions and it needs restrictive rules. Jeffery [51] designed an RFID middleware for the data cleaning between a heterogeneous sensor and upper application. The developed method is adaptive and applicable to unreliable RFID with the stream data smoothing; this method can only process data cleaning for single reading and writing device. Barjesh [48] proposed a data cleaning, transformation and loading technique. It was implemented based on the probability theory. There is no further related research on data filtering of multiple readers. It has been found that all of the existing algorithms have their limitations in solving specific programs, but the solutions are not comprehensive and general. This paper will propose a comprehensive and efficient data cleaning algorithm using the correlations of time and space among readers and tags.

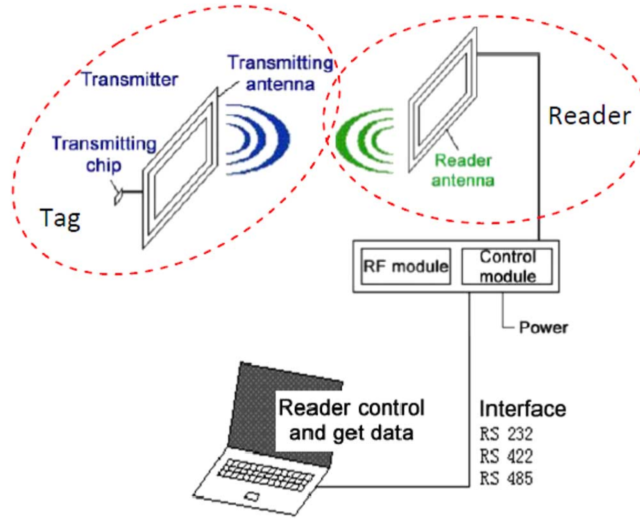

Fig. 1. Working principle of RFID.

III. Architecture for Integration of RFID and WSN

Here, the working principles of RFIDs and WSNs are briefly introduced, appropriate wireless communication standard is selected, and the system architecture has been proposed for an integration of RIFD and WSN.

A. RFID

RFID is to obtain identity data of targeted objected through RF signals; it is used to implement an automatic recognition and management of objects. As shown in Fig. 1, an RFID system consists of two parts: electronic *tag* and *reader*. An electronic tag is composed of a chip and an antenna; a tag communicates with a reader by the principle of inductance coupling or electromagnetic reflection. A reader is to read the identity label of a targeted object; it can also write the information on reading cards. An antenna can be attached to a tag, a reader, or to an interface to reader via a coaxial cable.

In a RFID system, a reader can scan multiple tags simultaneously. If a tag is found, its identifier will be recognized and transmitted to the information server; after the information server records the tag information, the tag identifier is further transmitted to the integration server [31]. Incoming RFID message and sensing data will be processed by the information manager and maintained in the event database.

B. Wireless Sensor Network (WSN)

A WSN consists of a large number of sensor nodes. In this project, sensor nodes are equipped with the capacities

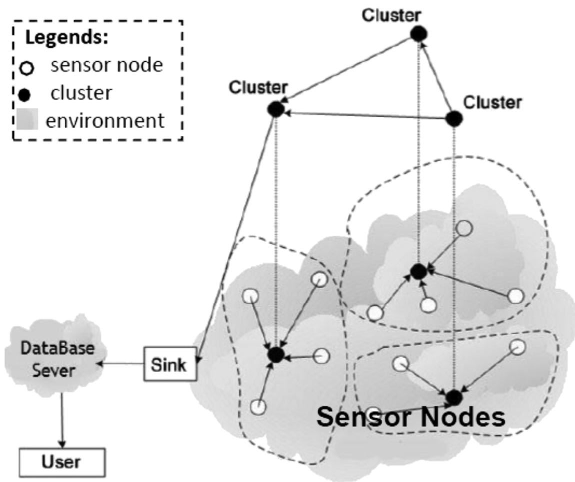

Fig. 2. Three-layer architecture of a WSN.

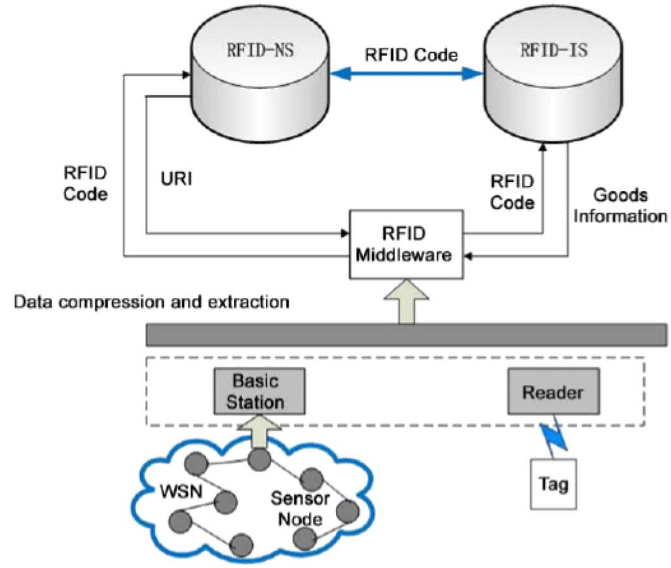

Fig. 3. Integration of RFID and WSN.

of message processing and data dissemination. Note that low energy consumption is a primary objective in the deployment of WSN. Two leading international standards for low-power wireless communications are Bluetooth (802.15.1) and ZigBee (802.15.4). As shown in Fig. 2, under system architecture of Bluetooth or Zigbee, a WSN consists of three layers: *sensor node layer*, *cluster layer*, and *sink node layer*. Note that, under the standard of IEEE 802.15.4, a sensor node and RFID can be treated equally in a sense that both of them can build peer-to-peer networks randomly for the communication in networks. In integrating the WSN and RFIDs, both readers and sensor nodes use wireless transceiver chips which are compatible with IEEE802.15.4.

C. Wireless Communication Protocols

The first task to integrate RFIDs with a WSN is to select a wireless communication standards and sensors. We choose one from two low-power wireless standards, i.e., Bluetooth and ZigBee. Bluetooth allows the creation and maintenance of a short-range personal area network (PAN). Bluetooth transfers data at the rate of 1 Mbps, the range of Bluetooth device is about 10 m. However, the main disadvantage of the Bluetooth is its relatively high energy consumption; usually, the Bluetooth cannot be used by sensors that are powered by a battery. On the other hand, a ZigBee-based WSN is a security network for a short distance communication based on the IEEE 802.15.4 standards. ZigBee has powerful networking capabilities. It is capable of supporting three types of self-organizing wireless networks: *star structure*, *network structure* and *cluster structure.* In addition, the ZigBee technology has the following characteristics: 1) it requires low power consumption; a sensor under a standby status can run more than six months; 2) it is cheap due to the opening standard; (3) it supports communication in a limited range from 10 to 100 m; 4) it provides a low rate and short latency; typically a response requires $15 \sim 30$ ms; 5) it has a high-capacity; each node can manage up to 254 child nodes; therefore, the ZigBee can have a maximized 64,516 nodes; 6) it possess high-security with the Advanced Encryption Standard AES-128 symmetric password and Access Control List (ACL). The ZigBee also has the anti-interference ability; moreover, the licensing of ZigBee network is free for industry. Due to the advantages of forming self-organized network systems and lower-cost, ZigBee technologies have been adopted for the WSN in this study.

The integration of RFID and WSN is shown as Fig. 3. The integration of the ZigBee sensors and RFID technology make it possible to identify the targeted object globally and perceive the status of the object in a real-time manner. The integration of WSNs and RFIDs can expand the scope of applications of the two technologies.

D. System Architecture

To take full advantages of WSNs and RFID technology, we propose a new robust system architecture which is shown in Fig. 4. It contains five logical layers: *physical layer*, *data link layer*, *network layer*, *transport layer*, and *application layer*. The functions at each layer are explained below.

1) **Physical layer**. The functions in the physical layer include channel selection, signal monitoring, sending and receiving message. The design goal in this layer is to minimize the energy consumption and increase the link capacity. A working channel can be chosen from 16 channels with rate ranging from 250 KB/s at 2.4 GHz.
2) **Data link layer**. This layer ensures that the physical data can be transmitted correctly; it also relates to the system spectrum efficiency and secure communication among system components. Based on the IEEE802 standard, a data link layer consists of two sublayers: logical link control (LLC) and media access control (MAC). LLC is to ensure the security and reliability of transmission. MAC provides the service interface with the point-to-point communication for upper layer to access physical channels. To reduce power consumption and adopt the caching mechanism, MAC sub-layer in IEEE 802.15.4 is based

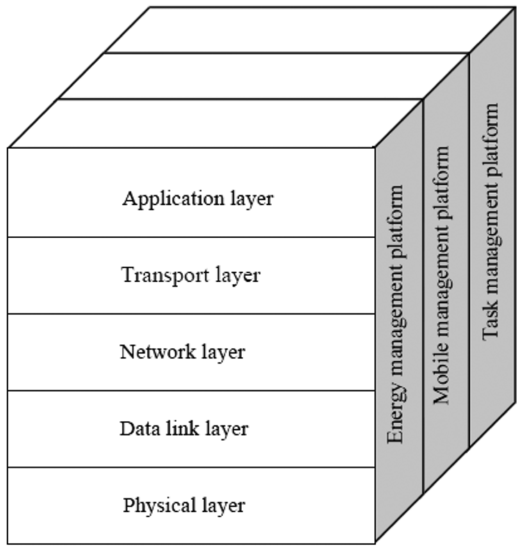

Fig. 4. Architecture for integration of RFID and WSN.

on 802.11 wireless local area network (WLAN) standards for carrier-sense multiple access/collision avoidance (CSMA/CA) access.

3) **Network layer**. The functions at this layer include packet routing and congestion control. Packet routing answers which adjacent node to which the current node should send its packet so that the data can arrive in its eventual destination as quickly as possible. The selection of packet routing may be based on the shortest time, the minimized number of hops or the shortest distance. Congestion occurs when a node is carrying so much data that its quality of service deteriorates. Deteriorated quality may be caused by queuing delay, packet loss or the blocking of new connections. Congestion control is to avoid congestion collapse.
4) **Transport layer**. The functions of this layer are flow control, error control, and quality control for reliable transmission service. The network layer of ZigBee can be used as this layer. The routing protocols are based on *ad hoc* technology; it has similar characteristics of low energy consumption at the bottom layer of IEEE802.15.4 standard; meanwhile, it can help the organization and maintenance of the network.
5) **Application layer**. The functions of this layer ensure safe data transmission and provide required services for the given application. An abstract interface is defined for the ZigBee network; the network platform also provides the application programming interface (API). APIs are used to define the rules such as how the application interfaces should be integrated into the ZigBee protocol stack.

In our prototype system, the locations of readers are fixed. Therefore, the energy consumptions of sensor nodes will not be a concern since they can be continually loaded and data fusion and data management can be done in the readers. Readers transmit information that can be collected and initially fused to a middleware server, then to be delivered to an application server. Note that our work is preliminary and limited to the integrated architecture RFID and WSN. Our future research will aim at providing solutions to the problems mentioned in the Section II-B.

IV. New Data Cleaning Algorithm

Here, the issue related to redundant data will be specially taken into consideration to improve the efficiency of data communication. A new data cleaning algorithm is presented, simulated, and validated.

A. Assumptions and Definitions

We assume there are m readers, $m \times n$ fixed reference tags whose attributes are known, and l tags for arbitration. Each reader contains n reference tags which can be detected and located in its working area of the reader. For the algorithm, the following concepts and definitions are defined.

$G_{j,k}$ Signal intensity of reference tag k which belongs to reader j, $j \in (1, \dots m)$, $k \in (1, \dots n)$.

$W_{i,j}$ Signal intensity of tag i waiting for arbitration on reader j, $i \in (1, \dots l)$, $j \in (1, \dots m)$.

Definition 1: $D_{i,j}$ is the Euclidean distance between the signal intensity of tag i waiting for arbitration on reader j and the signal intensity of m reference tags of reader j. If the value of $D_{i,j}$ is small to reader j, it more likely will belong to the reader of the tag i:

$$D_{i,j} = \sqrt{\sum_{k=1}^{n} (W_{i,j} - G_{j,k})^2}, \quad i \in (1 \cdots l), j \in (1 \cdots m). \tag{1}$$

Definition 2: A triple $d(Rid, Tid, \tau)$ is a set of original data. Rid is denoted as unique identification of the reader. Tid is denoted as unique identification of the tag. τ is timestamp which the tag is detected. Through a triple d, the mapping relationship of the RFID system between physical device and logic identity can be built.

Definition 3: Cross-redundant data is produced by some readers which locate at the same working area at certain moment. Cross-redundant data satisfy the following two conditions.

1) For the two arbitrary triples $d_i(Rid_i, Tid_i, \tau_i)$ and $d_j(Rid_j, Tid_j, \tau_j)$ from the same cross space, the condition of $(Rid_i \neq Rid_j) \cap (Tid_i = Tid_j)$ is satisfied.
2) At the same time, the relation of $(\tau_i = \tau_j) \cap (|\tau_i - \tau_j| \leq \sigma)$ is also satisfied, where σ is the time threshold.

Definition 4: Affiliation is possible as tag i responds to reader j within the induction scope of reader j at the moment t; further, we denote it as follows:

$$F(i,j,t) = \frac{1}{3} \sum_{k=0}^{2} p(i,j,t-k) \quad i \in (1 \cdots l), j \in (1 \cdots m) \tag{2}$$

where $p(i,j,t)$ is the frequency that reader j links to tag i at the moment t.

B. Improved Cross-Redundant Data Cleaning Algorithm (ICRDC)

With constantly incoming tuples, a structure needs to be maintained incrementally. This structure is called cross tags list (CTL) in the memory. The multilevel index of the outer layer can guarantee the performance of the search operation. The tuple queue ensures the performance of inserting and deleting operations. The mechanism of time sliding window can complete the arbitration using the units of time window at the same time on many orderly tuple.

The steps involved in this algorithm are as follows and they are further illustrated in Fig. 5.

1) Read the membership of configuration files that bind with reference tags and readers, create an initial CTL.
2) Update CTL in time from the RFID data stream for uninterrupted production.
3) Check if existing tags of waiting arbitration are nearby reference tags in CTL. If the answer is no, go to step 8); if there are some arbitration tags going to step 4).
4) Based on the sliding window, detect the tuple cache queue in tuple groups, and check if the tuple is redundant or not using the definition and inspection standard in definition 2. If it does not satisfy the condition, return to step 2; otherwise, go to step 5).
5) Compute the affiliation $F(i,j,t)$ that tag i responds to reader j at the moment t.
6) Compute the signal intensity W_{ij} to see that tag i of waiting for arbitration is relative to the reader j that already detected tag i in sliding window w.
7) Calculate the signal intensity vector $G_j = (G_{j,1}, G_{j,2}, \ldots, G_{j,n})$; it denotes whether or not n reference tags belongs to reader j.
8) Calculate the Euclidean distance that tag i of waiting for arbitration with respect to $G_j = (G_{j,1}, G_{j,2}, \ldots, G_{j,n})$. The method of minimum relative position and $F(i,j,t)$ to arbitrate the reader of cross redundant data are applied. Through an exclusive process, the cross redundant data can be eliminated.
9) Filter the expired cross information tuple in CTL to maintain a reasonable memory and then return to step 2).

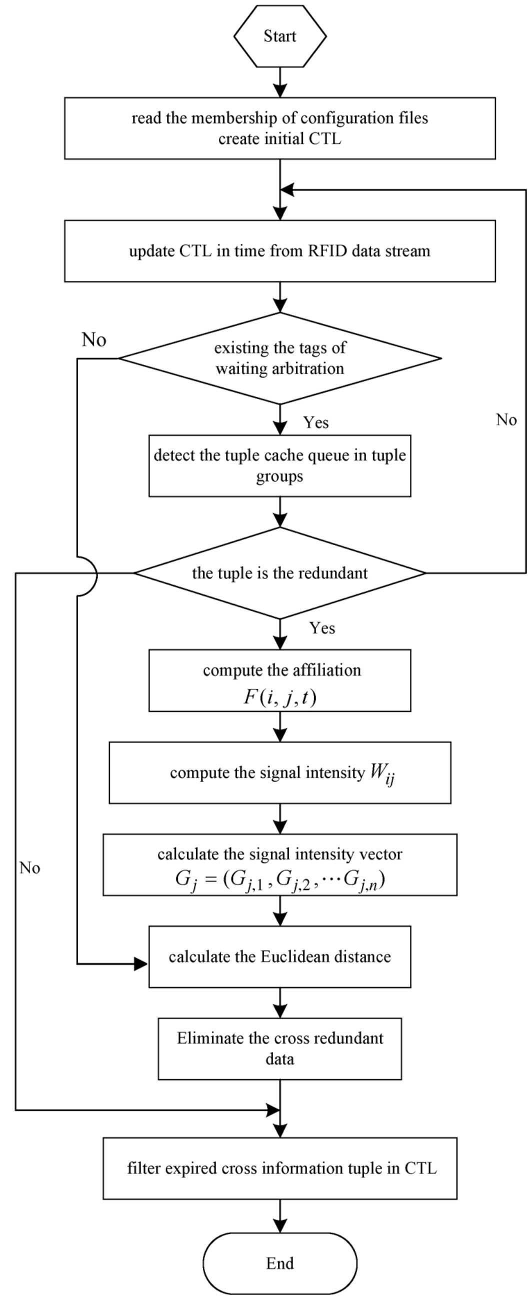

Fig. 5. Flow chart of ICRDC algorithm.

C. Numerical Analysis

To evaluate the performance of the proposed algorithm, experimental setups similar to other researchers have been developed [47], [53]. The performance of our algorithm, especially *compressibility* and *accuracy*, has been taken into consideration and the results from the developed algorithm are compared with those obtained by a state-of-the-art data cleaning algorithm SMURF.

Statistical smoothing for unreliable RFID data (SMURF) was proposed by Jeffery *et al.* [47] for cleaning raw RFID data streams. It was claimed as the first declarative data filter. A unique feature of SMURF is its adaptability of automatically adjusting the window size based on the acquired readings. In SMURF, the statistical based sampling method can distinguish if weaken reading is caused by dropping or a moved tag. The data stream of RFID is modeled as the random sample of the readings in sensing area. By analyzing the sample with the statistical theory, SMURF is implemented at the low-level data processing of RFID for cleaning and spatial processes. Two versions of SMURF are for: 1) adaptive pre-tag cleaning and 2) adaptive multi-tag cleaning, respectively. Here, the second version is used for comparison. Interested readers may review details of the SMURF in [47].

The RFID networks with different numbers of sensor nodes have been tested; five different experimental areas are set up where the locations of readers and tags are randomly generated. To generate random locations of readers and tags in a RFID network, no readers or tags are allowed to share a position. Table I shows the parameters specified for the simulation.

We compare compressibility of accuracy from the new algorithm with that from SMURF. Table II shows the comparison

TABLE I
SOME PARAMETERS OF SIMULATION

Working Area(m^2)	Number of Readers	Number of Tags
40×40	50	200
60×60	100	350
70×70	200	500
80×80	300	700
100×100	400	800

TABLE II
COMPARISON OF RESULTS FROM ICRDC AND SMURF

Number of Readers	Compressibility (%)		Accuracy (%)	
	ICRDC	SMURF	ICRDC	SMURF
50	2.15	1.4	4.5	3.1
100	4.5	3.2	5.9	3.9
200	7.3	6.1	7.2	7.2
300	9.9	7.9	10.5	8.9
400	11.5	8.7	14.1	11.87
Average	7.07	5.46	8.44	6.994

of the simulation results for five experiments. The observations from Table II are as follows. With an increase of the experimental areas or number of readers and tags, the rate of compressibility and accuracy is improved by ICRDC or SMURF quickly. The average rates of the compressibility for ICRDC and SMURF are 7.07% and 5.46%, respectively. The average rates of the accuracy for them are 8.44% and 6.994%, respectively. For both algorithms, they are effective to improve the compressibility and accuracy of redundant data, but the improvement from ICRDC is more significant. Fig. 6 has shown that the compressibility and accuracy of redundant data by the proposed ICRDC are better than those from SMURF. The experiments have shown that ICRDC can clean redundant RFID data effectively and, more importantly, will not affect the integrity of RFID data. Note that effectiveness of ICRDC is validated by numerical simulation; it is not supported by theoretical proves. Its performance in other complicated cases is yet to be tested.

V. APPLICATIONS OF INTEGRATED ARCHITECTURE

The developed integrated architecture and new data cleaning algorithm can be applied in many different applications. In this section, its application as a relief supply management system is discussed as a case study. One motivation to use a medical application as a case study is that RFID and WSN for medical applications have attracted numerous attentions. The recent progress in applying integrated information systems in healthcare industry has been reported in [54] and [55].

To rescue the affected population effectively, it is important to send relief supplies timely and manage the process wisely after some disasters or unexpected events occur [56]–[59]. It is always difficult to monitor and manage the distributions of relief supplies on wide geographically distributed areas. With the rapid development of the WSN and RFID technologies, the implementation of intelligent logistic management and storage systems become possible; such systems will play a significant role in acquiring information regarding resources, scheduling

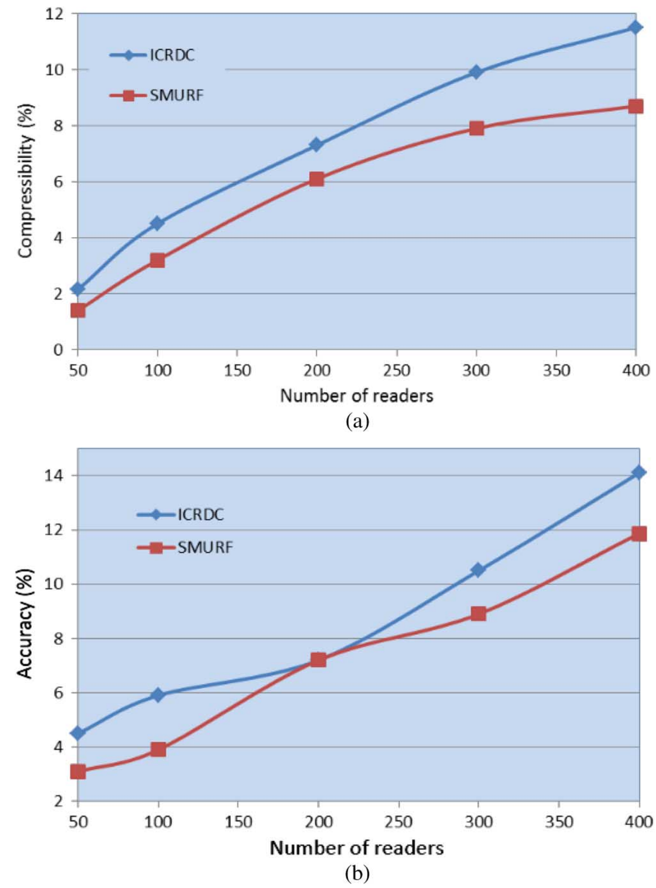

Fig. 6. Comparison of the results from ICRDC and SMURF. (a) Compressibility. (b) Accuracy.

and deploying emerging goods automatically. Similar to an EIS for manufacturing systems, an intelligent storage management system has been proposed based on an integration of WSN and RFID technologies. It collects real-time data, analyzes, assesses, and monitors the processes of distribution and transportation to ensure relief supplies are distributed appropriately in time and quality manner.

A. Design Framework

As shown in Fig. 7, the proposed integrated system consists of four modules: *relief supplies detection*, *relief supplies control*, *relief supplies warehousing*, and *relief supplies decision support*.

Relief supplies detection module is to detect all of the sensors and collect data including environmental data. The sources of data can be various sensors, attributes stored in RFID tag, and the locations of the relief supplies. All of the data is transmitted to the host data distribution center through the ZigBee-based WSN.

Relief supplies control module keeps the data from RFID tags and the environmental data received by sensors such as temperature, humidity, and pressure. This module also conducts comprehensive analysis and assessment. It is equipped with a software system for real-time monitoring and display. The software system can verify the attributes and control the distributing process.

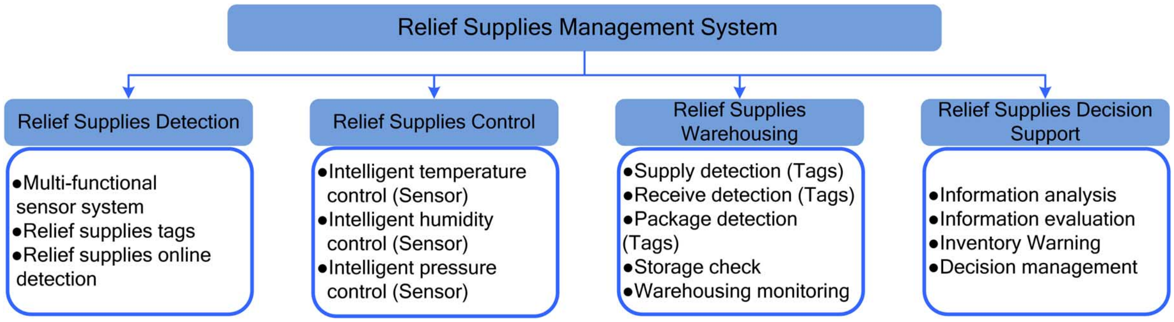

Fig. 7. Framework of relief supplies management system.

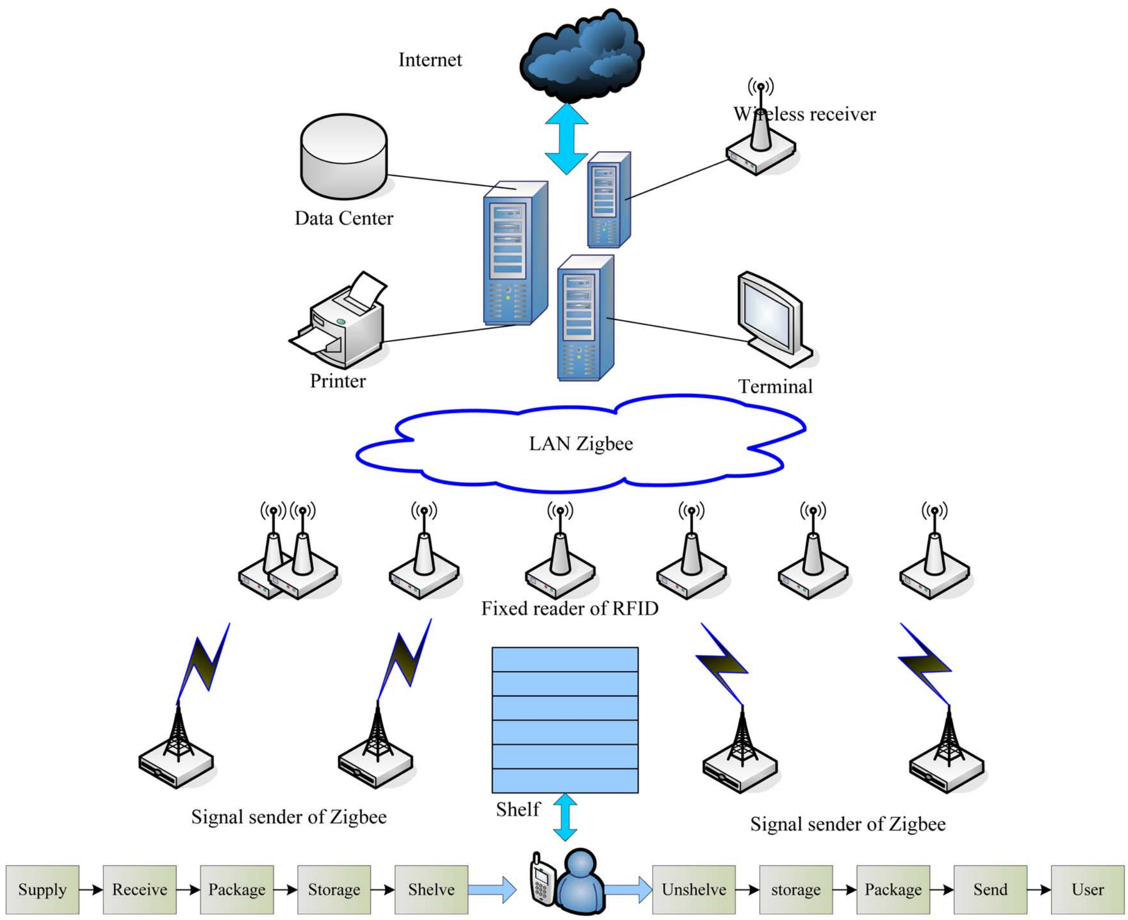

Fig. 8. Deployment of relief supplies based on Zigbee and RFID.

Relief supplies warehousing module is to manage the relief supplies to be put in specified storages. It monitors the transportation of relief supplies from suppliers to storage. If some mistakes are found during the monitoring process, this module suggests the solution for the correction.

Decision support module is to analyze transmission data using the data mining technology. It focuses on the basic attributes of relief supplies; it is capable of rescheduling the distribution based on the latest needs of the various settlements. It verifies the locations of goods to determine whether or not the goods have been transported to destinations.

B. Implementation of Storage Management

The deployment of relief supplies management based on ZigBee and RFID technology is shown in Fig. 8. In order to manage the relief supplies more effectively, a number of readers and terminals must be set in the warehouse. The steps are given here.

1) For each object, an RFID tag or other type of tag is attached. Readers are installed at the entrance of the channel warehouse. It ensures the reader to obtain required information from tags when goods pass through the entrance.
2) In the warehouse, a certain number of RFID handheld/car terminals are set among shelves and exits. It is convenient to check inventory, track objects, retrieve accurate the information of relief supplies in the storage management system. It is very important that this network can ensure to acquire accurate data in the warehouse.

3) In the storage areas, based on the size of area, the distance signal transceiver module is set to form a backbone wireless network. Especially at the main drive roads, a number of ZigBee nodes are installed. When a vehicle with an integrated label passes by the coverage area, the monitoring and controlling can find the location of vehicle in real time.

VI. Conclusion

The requirements of decentralization, high adaptability, and flexibility of next-generation EISs have been discussed [60]–[77]. It has been observed that existing EISs are mostly developed based upon hierarchical architecture, which is not flexible to accommodate changes and uncertainties in today's turbulent and dynamic environments. EISs require sufficient and real-time data. It is critical to develop effective data acquisition systems for EISs. With the considerations of dynamic, distributed, and decentralized environments, RFIDs and WSNs become the better choices for many applications over traditional wired networks.

In this paper, the literature on WSNs and RFIDs has been thoroughly reviewed. Most existing research is for specific applications which lack generality. In particular, there are no comprehensive algorithms to deal with the redundant data from multiple readers appropriately. In this paper, a five-layer system architecture is developed to integrate WSNs and the RFID systems. Bluetooth and ZigBee technologies are selected as the communication protocol of the WSNs to meet the requirements of large number of sensor nodes, wide areas, and low cost. To eliminate redundant data in the integrated WSN, an improved cross-redundant algorithm (ICRDC) is presented. Its effectiveness has been validated via simulation and comparison study: ICRDC can improve the data compressibility and accuracy more effectively in comparison to the SMURF. To illustrate the feasibility and effectiveness of integrated architecture and new algorithm, they have been proposed to be applied in relief supply management.

While the feasibility of the integration of RFID and WSN has been validated in this study, much work for meeting the challenges discussed in the Section II-B needs continuous effort before the system can become applicable to more challenging situations and be commercialized. Although the efficiency of the developed ICRDC has been verified in the case study, it is required to be expanded and tested in other applications. We plan to continue our work in these directions to improve the developed algorithm and the integrated information systems.

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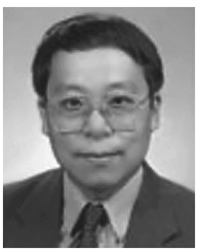

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